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Barabash et al.

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(54) **VSWR ESTIMATION USING CORRELATION TO SUPPRESS EXTERNAL INTERFERENCE**

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CPC ***H04B 17/101*** (2015.01); ***G01R 27/06*** (2013.01); ***H04B 1/0458*** (2013.01); ***H04B 1/0475*** (2013.01); ***H04B 17/103*** (2015.01); ***H04B 17/12*** (2015.01); ***H04W 24/06*** (2013.01)

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CPC H04W 24/06; H04B 17/12; H04B 17/101; H04B 1/0475
USPC 455/67.4, 226.1, 423.424, 124, 67.14, 455/423, 424, 67.11, 67.16; 343/703
See application file for complete search history.

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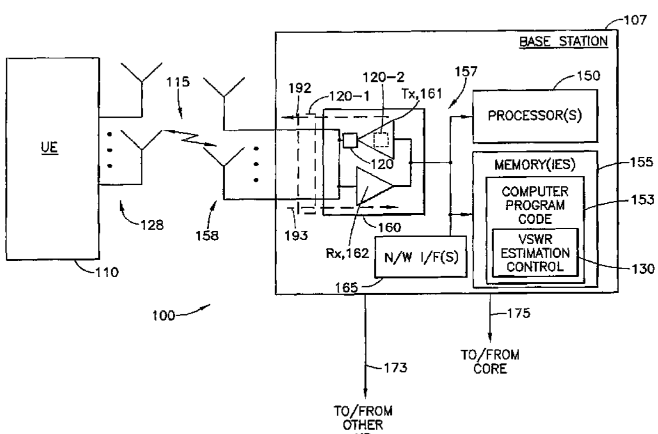
(74) *Attorney, Agent, or Firm* — Harrington & Smith

(57) **ABSTRACT**

A method includes accessing sets of correlation values, each set corresponding to a correlation performed between a number of first samples and a same number of second samples. The sets of correlation values were determined by aligning the number of the first samples with selected second samples and sliding the number of first samples across the second samples to select different sets of the second samples. The first samples are samples of a forward signal transmitted over a cable/connector system to one or more antennas, and the second samples are samples of a reflected RF signal that comprises a reflected version of the forward signal. The method includes determining a maximum value from the plurality of sets of correlation values, and associating the maximum value with a return loss of the cable/connector system. Apparatus, computer programs, and program products are also disclosed.

20 Claims, 14 Drawing Sheets



(51) **Int. Cl.**
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H04B 17/12 (2015.01)

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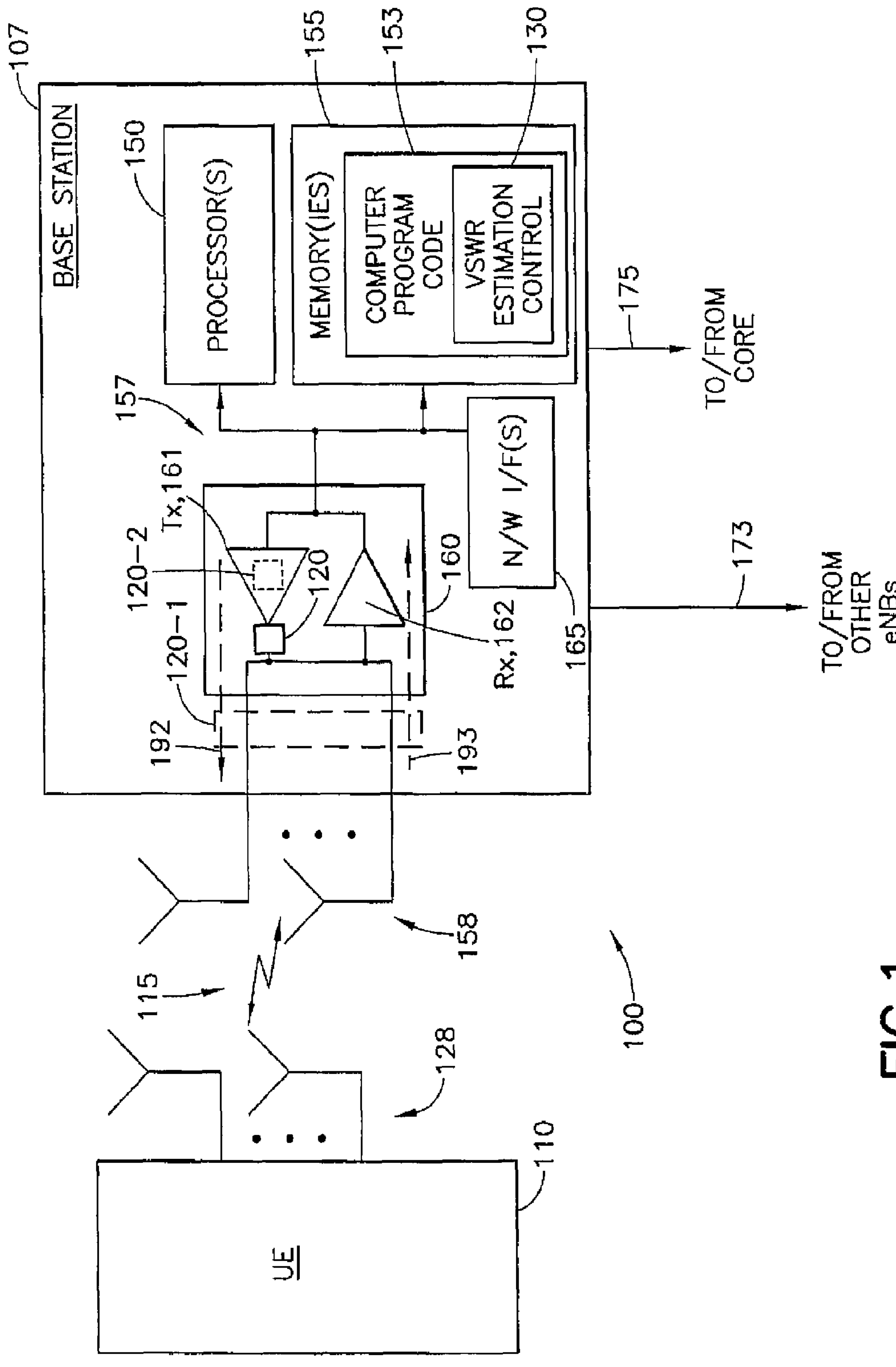

107
BASE STATION
150
PROCESSOR(S)
155
153
130
MEMORY(IES)
COMPUTER PROGRAM CODE
VSWR ESTIMATION CONTROL
175
TO/FROM CORE
157
Tx,161
120-2
120
120-1
160
N/W I/F(S)
Rx,162
165
173
TO/FROM OTHER eNBs
192
193
158
115
128
100
110
UE

FIG.1

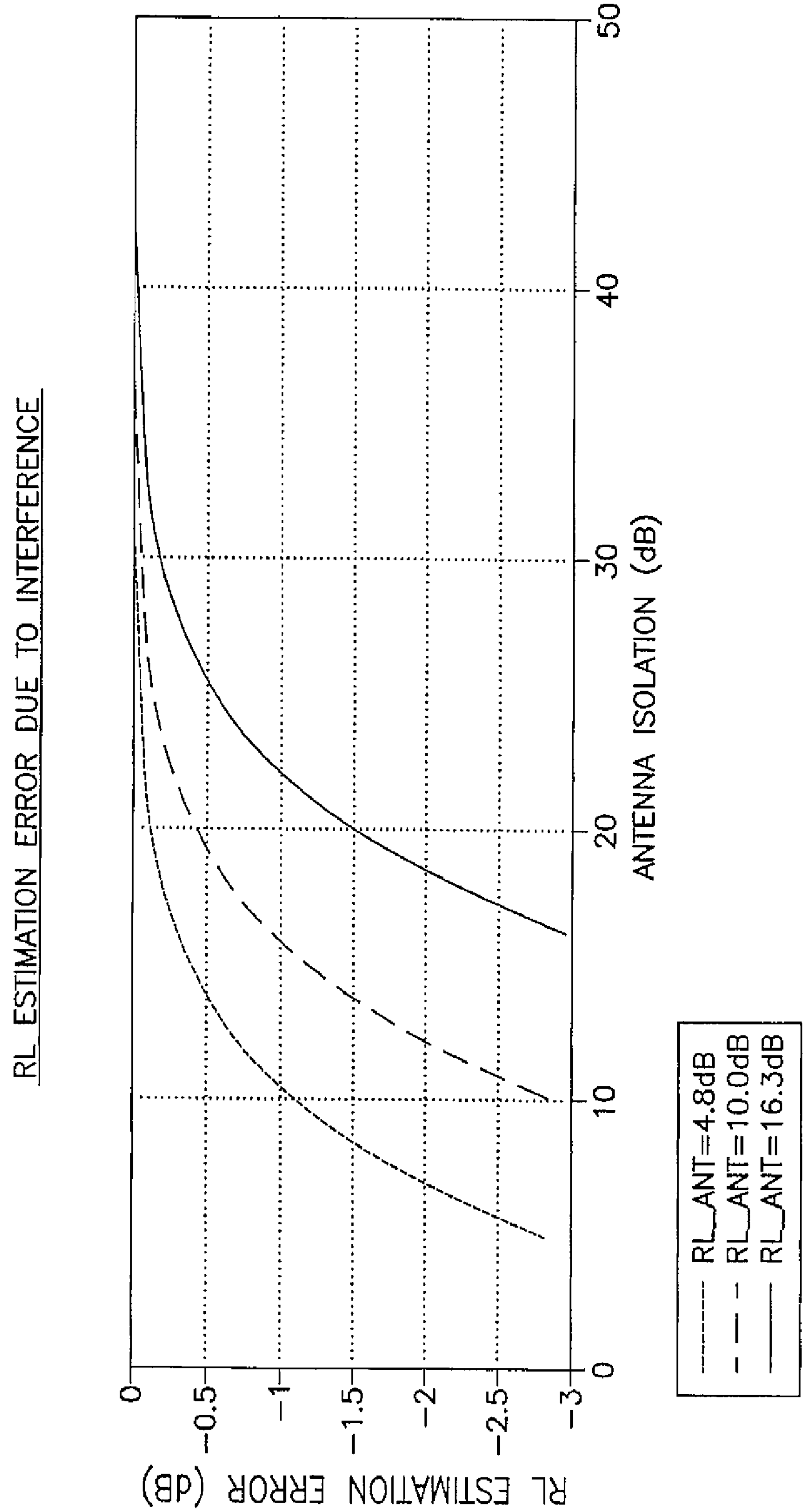
RL ESTIMATION ERROR DUE TO INTERFERENCE
RL ESTIMATION ERROR (dB)
0
-0.5
-1
-1.5
-2
-2.5
-3
ANTENNA ISOLATION (dB)
0
10
20
30
40
50
RL_ANT=4.8dB
RL_ANT=10.0dB
RL_ANT=16.3dB

FIG.2

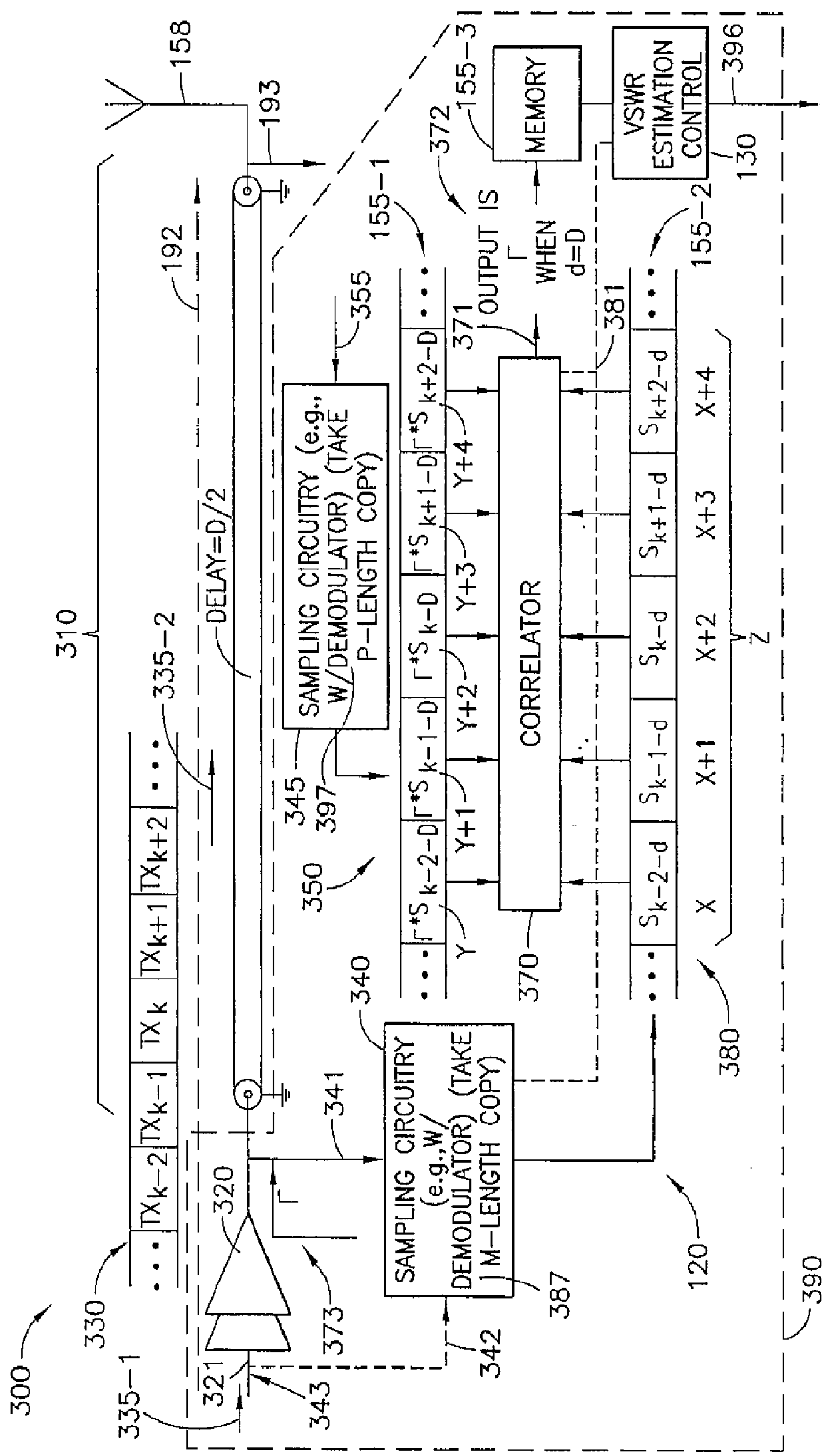
300
310
158
193
192
DELAY=D/2
335-1
335-2
330
TXk-2
TXk-1
TXk
TXk+1
TXk+2
320
321
343
342
373
341
SAMPLING CIRCUITRY (e.g.,W/ DEMODULATOR) (TAKE M-LENGTH COPY)
340
387
SAMPLING CIRCUITRY (e.g., W/DEMODULATOR) (TAKE P-LENGTH COPY)
345
397
355
350
155-1
Γ*Sk-2-D
Γ*Sk-1-D
Γ*Sk-D
Γ*Sk+1-D
Γ*Sk+2-D
Y
Y+1
Y+2
Y+3
Y+4
CORRELATOR
370
371
381
OUTPUT IS Γ WHEN d=D
372
MEMORY
155-3
VSWR ESTIMATION CONTROL
130
396
155-2
Sk-2-d
Sk-1-d
Sk-d
Sk+1-d
Sk+2-d
X
X+1
X+2
X+3
X+4
Z
380
120
390

FIG.3A

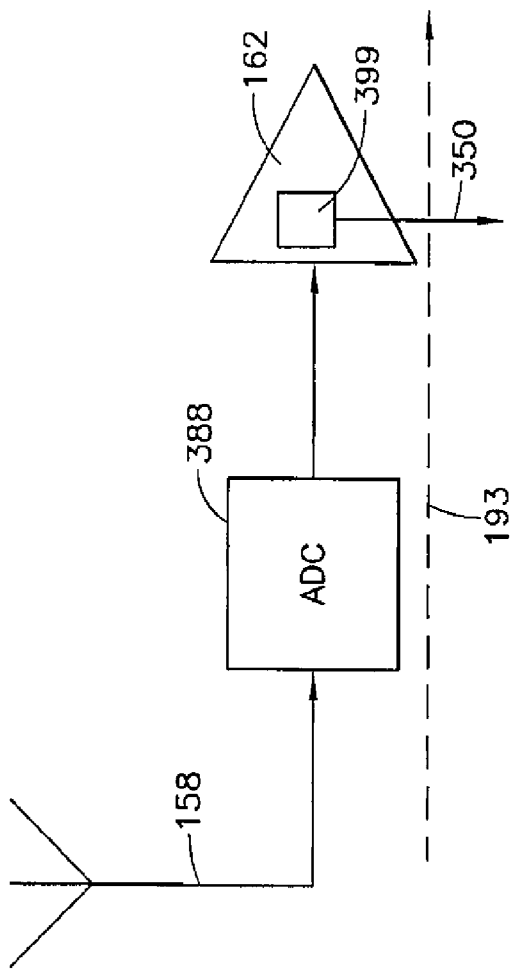

FIG.3B

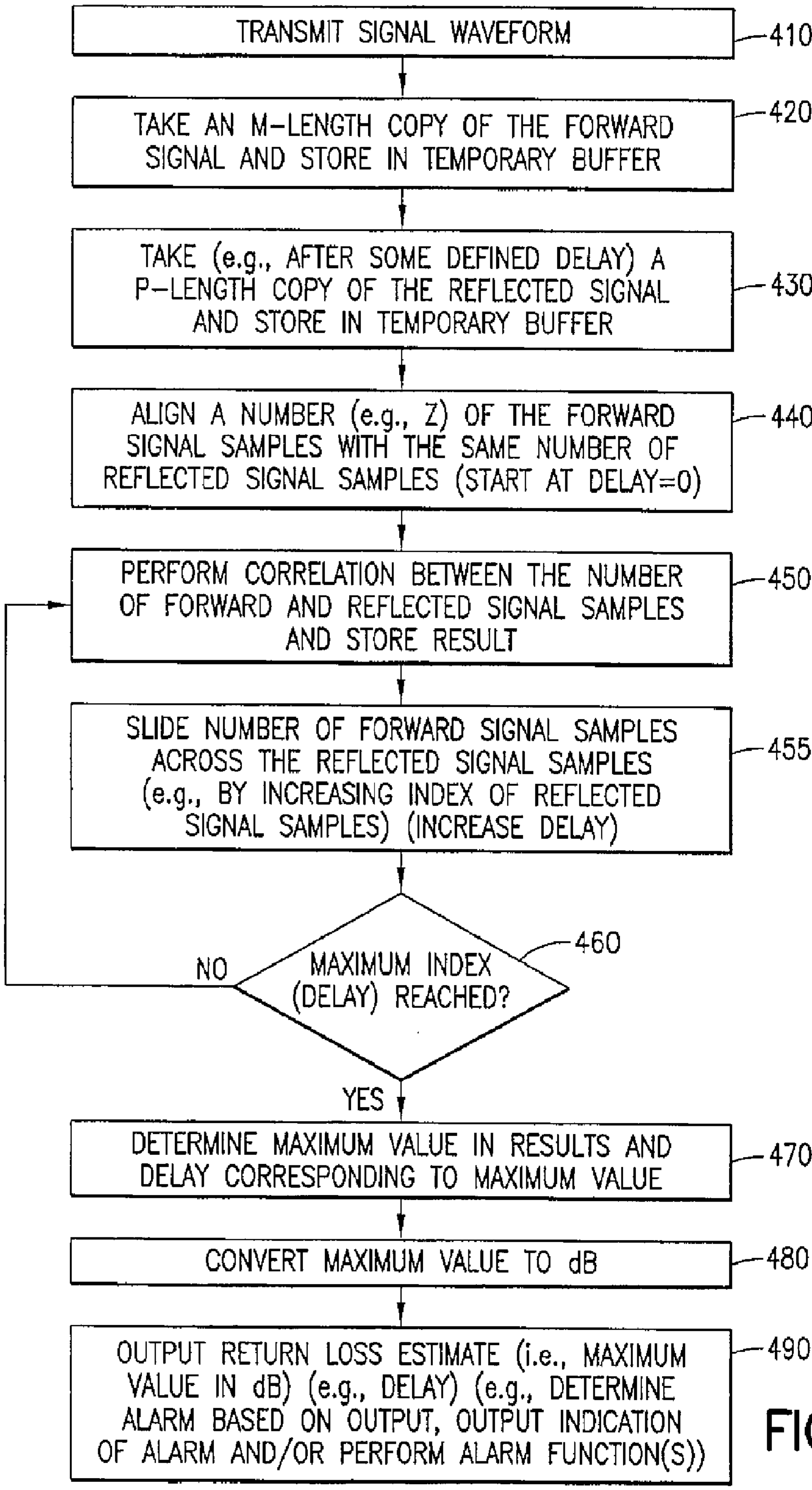
TRANSMIT SIGNAL WAVEFORM
410
TAKE AN M-LENGTH COPY OF THE FORWARD SIGNAL AND STORE IN TEMPORARY BUFFER
420
TAKE (e.g., AFTER SOME DEFINED DELAY) A P-LENGTH COPY OF THE REFLECTED SIGNAL AND STORE IN TEMPORARY BUFFER
430
ALIGN A NUMBER (e.g., Z) OF THE FORWARD SIGNAL SAMPLES WITH THE SAME NUMBER OF REFLECTED SIGNAL SAMPLES (START AT DELAY=0)
440
PERFORM CORRELATION BETWEEN THE NUMBER OF FORWARD AND REFLECTED SIGNAL SAMPLES AND STORE RESULT
450
SLIDE NUMBER OF FORWARD SIGNAL SAMPLES ACROSS THE REFLECTED SIGNAL SAMPLES (e.g., BY INCREASING INDEX OF REFLECTED SIGNAL SAMPLES) (INCREASE DELAY)
455
MAXIMUM INDEX (DELAY) REACHED?
460
NO
YES
DETERMINE MAXIMUM VALUE IN RESULTS AND DELAY CORRESPONDING TO MAXIMUM VALUE
470
CONVERT MAXIMUM VALUE TO dB
480
OUTPUT RETURN LOSS ESTIMATE (i.e., MAXIMUM VALUE IN dB) (e.g., DELAY) (e.g., DETERMINE ALARM BASED ON OUTPUT, OUTPUT INDICATION OF ALARM AND/OR PERFORM ALARM FUNCTION(S))
490

FIG.4

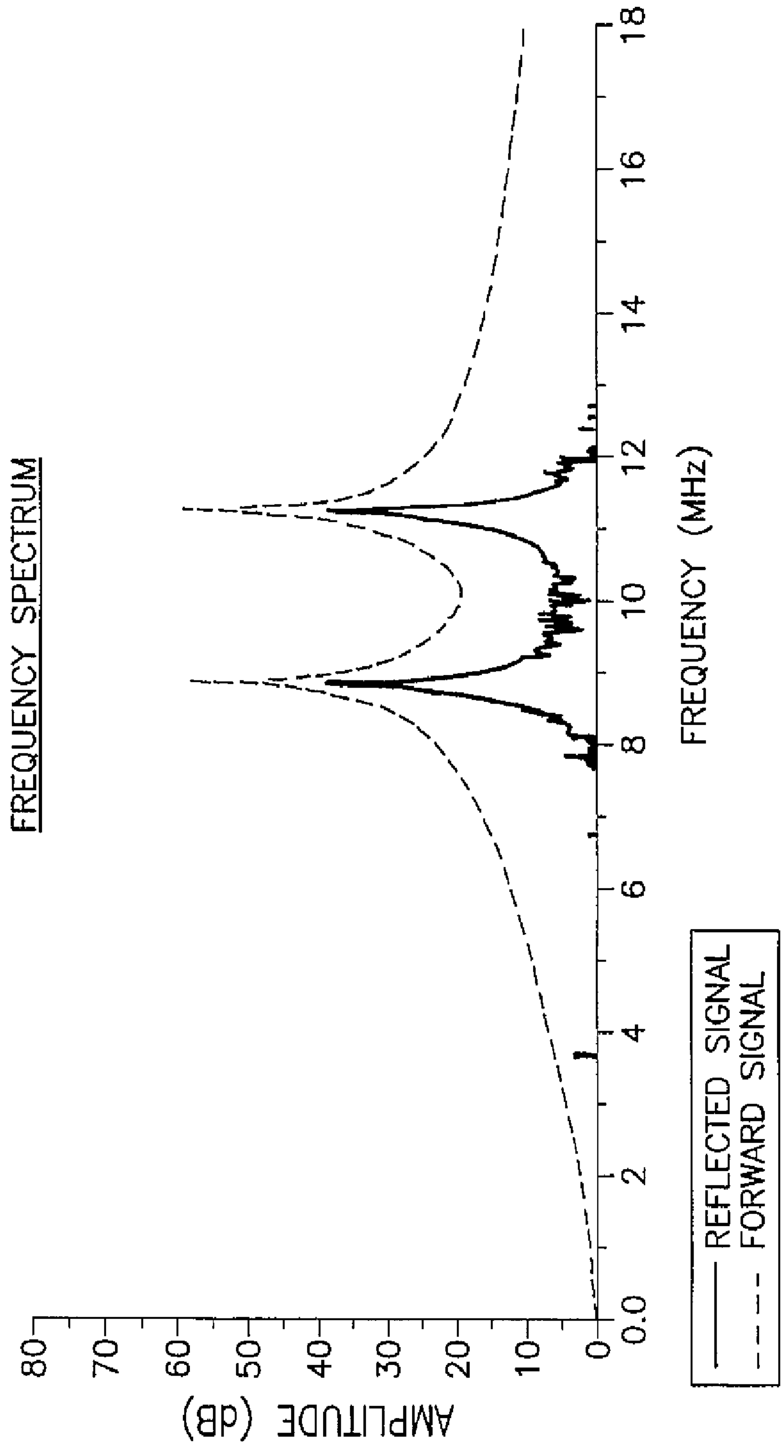
FREQUENCY SPECTRUM
AMPLITUDE (dB)
80
70
60
50
40
30
20
10
0
0.0
2
4
6
8
10
12
14
16
18
FREQUENCY (MHz)
REFLECTED SIGNAL
FORWARD SIGNAL

FIG.5A

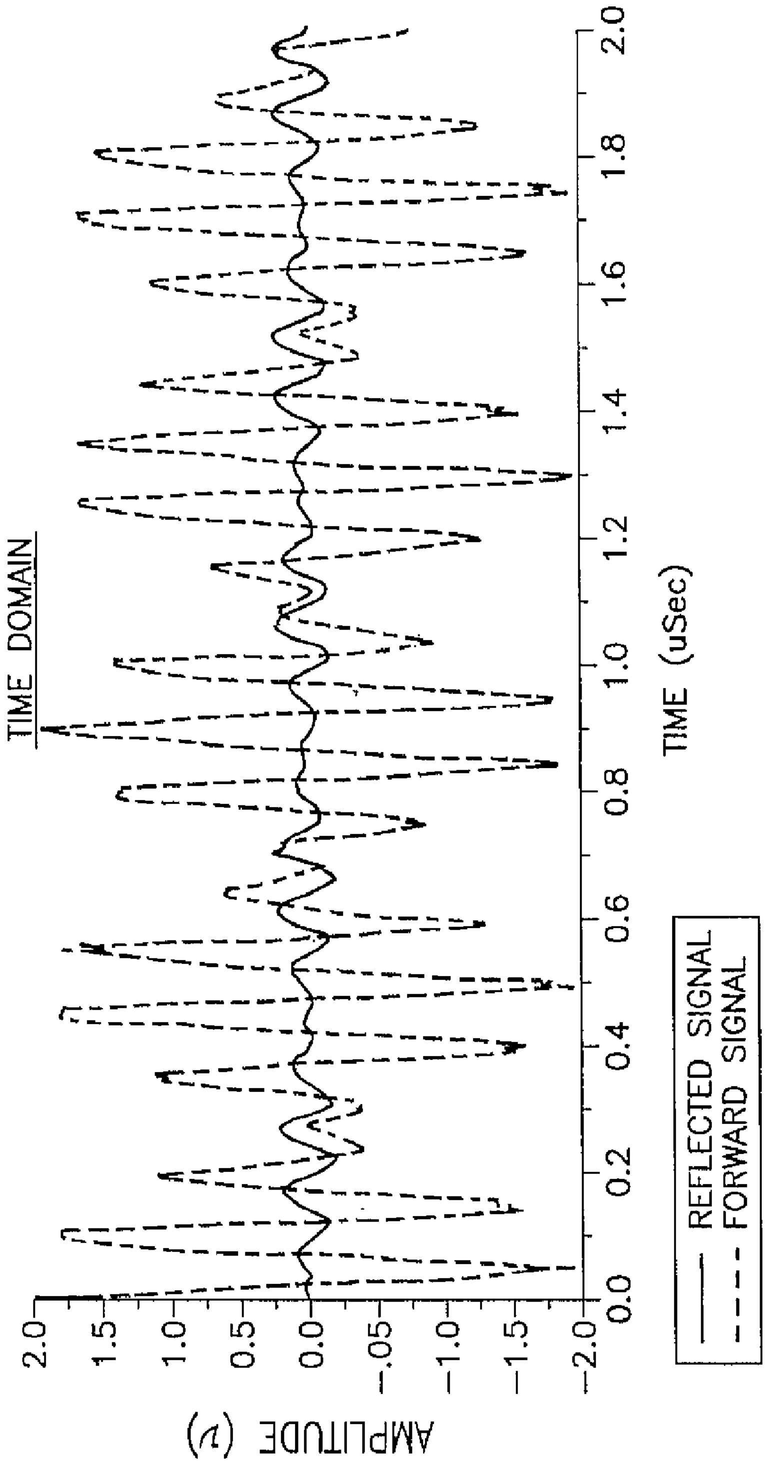
TIME DOMAIN
AMPLITUDE (v)
2.0
1.5
1.0
0.5
0.0
-.05
-1.0
-1.5
-2.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (uSec)
REFLECTED SIGNAL
FORWARD SIGNAL

FIG.5B

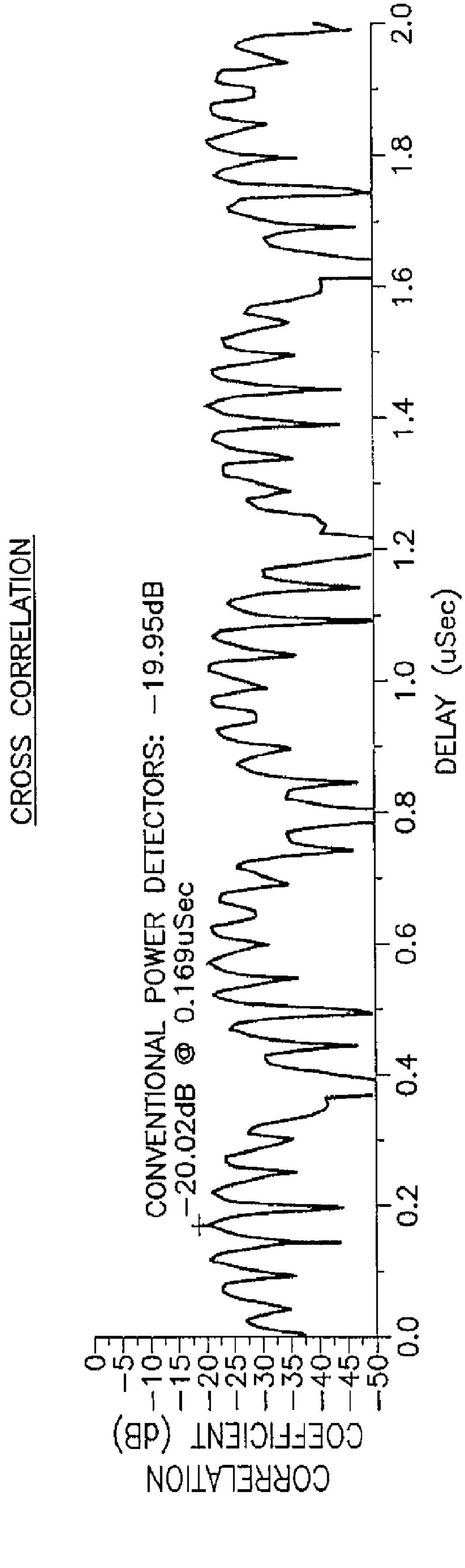
CROSS CORRELATION
CONVENTIONAL POWER DETECTORS: −19.95dB
−20.02dB @ 0.169uSec
CORRELATION COEFFICIENT (dB)
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DELAY (uSec)

FIG.5C

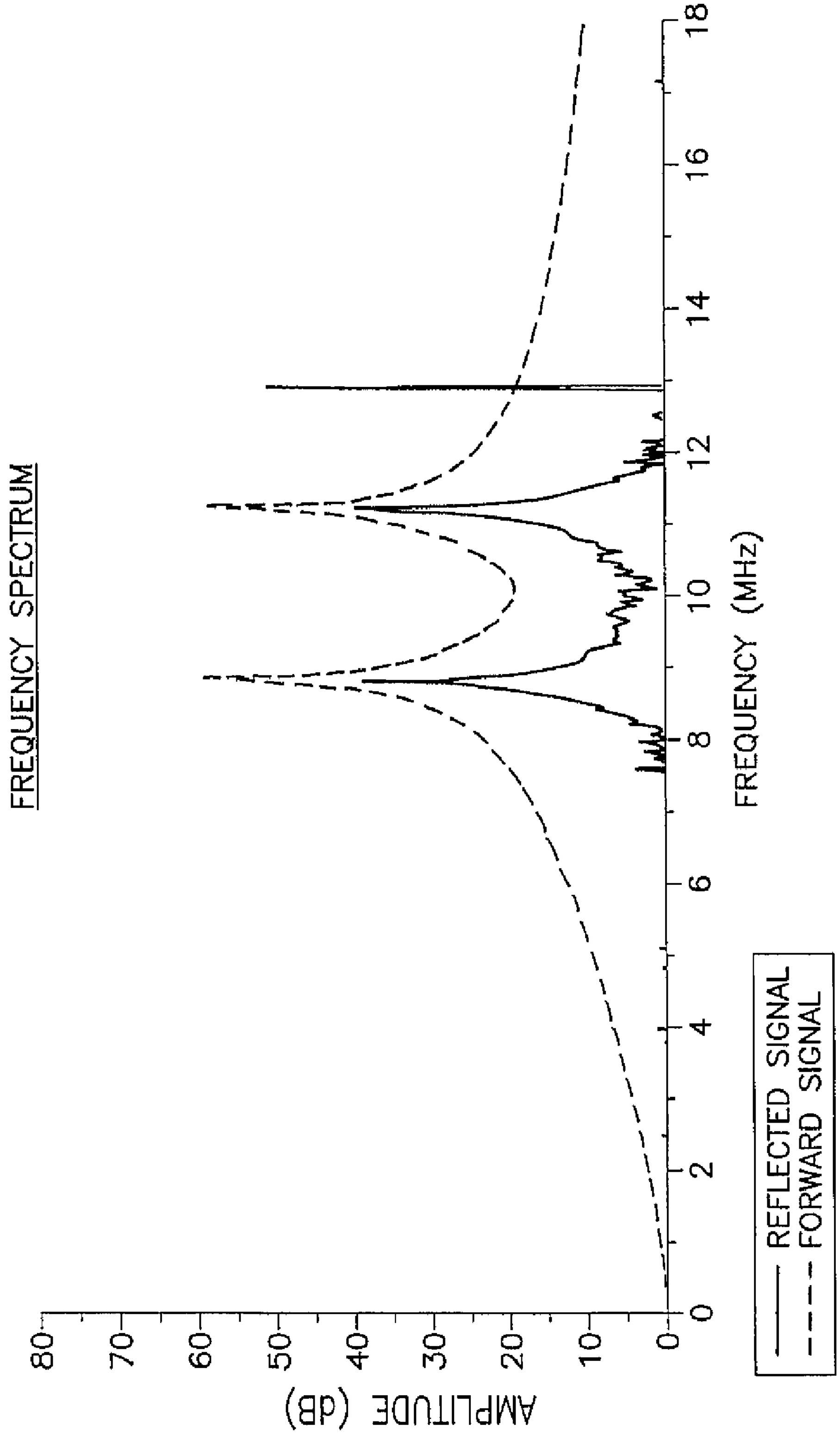
FREQUENCY SPECTRUM
AMPLITUDE (dB)
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
FREQUENCY (MHz)
REFLECTED SIGNAL
FORWARD SIGNAL

FIG.6A

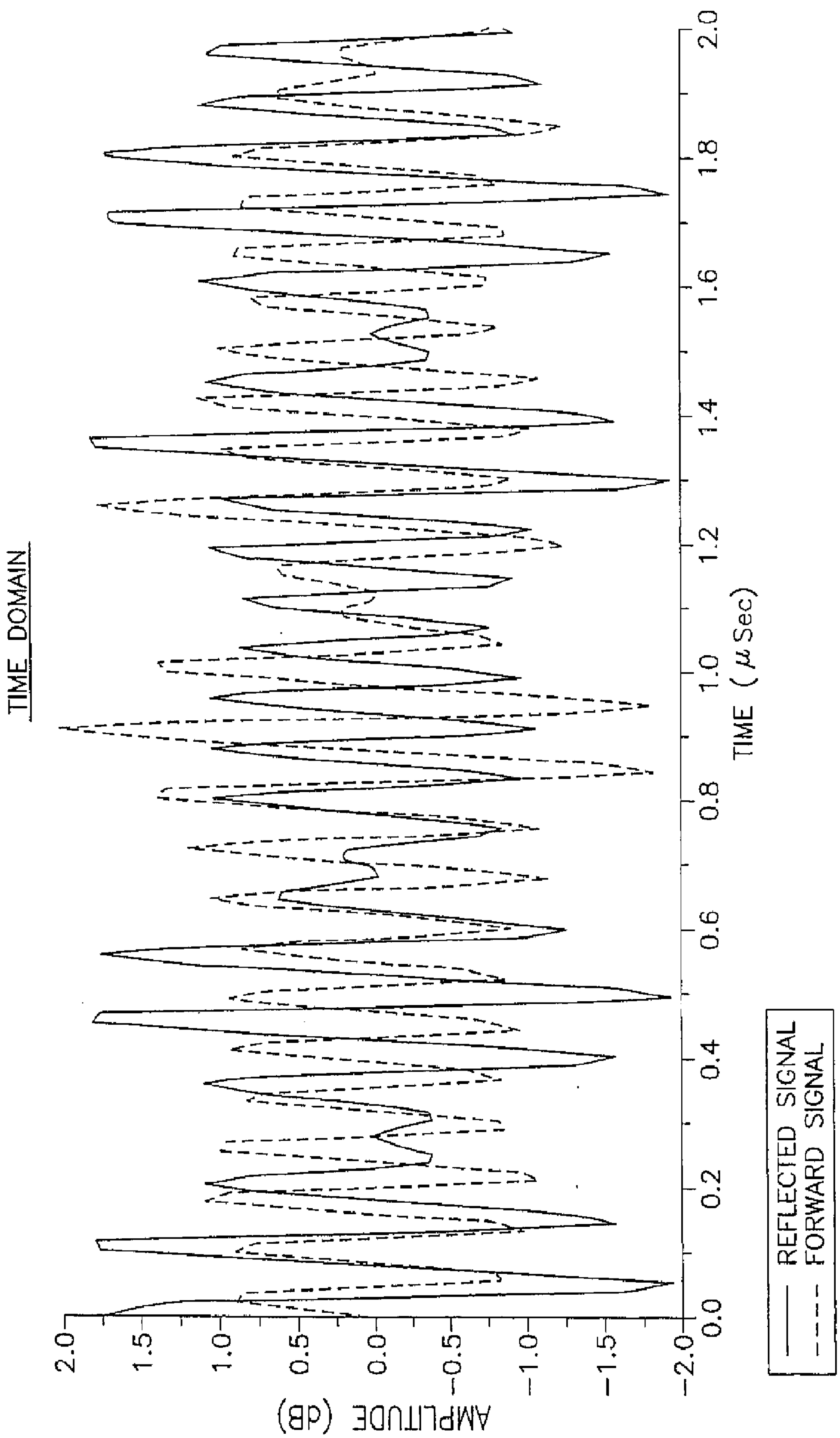
TIME DOMAIN
AMPLITUDE (dB)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (μ Sec)
REFLECTED SIGNAL
FORWARD SIGNAL

FIG.6B

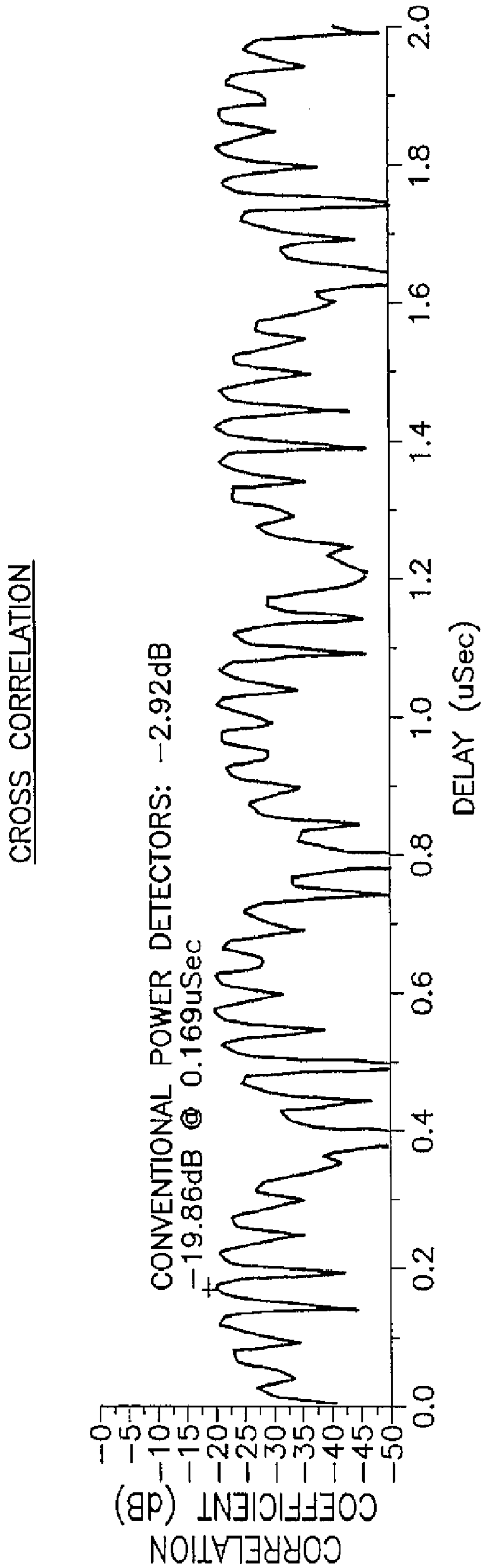
CROSS CORRELATION
CONVENTIONAL POWER DETECTORS: −2.92dB
−19.86dB @ 0.169uSec
CORRELATION COEFFICIENT (dB)
−0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DELAY (uSec)

FIG.6C

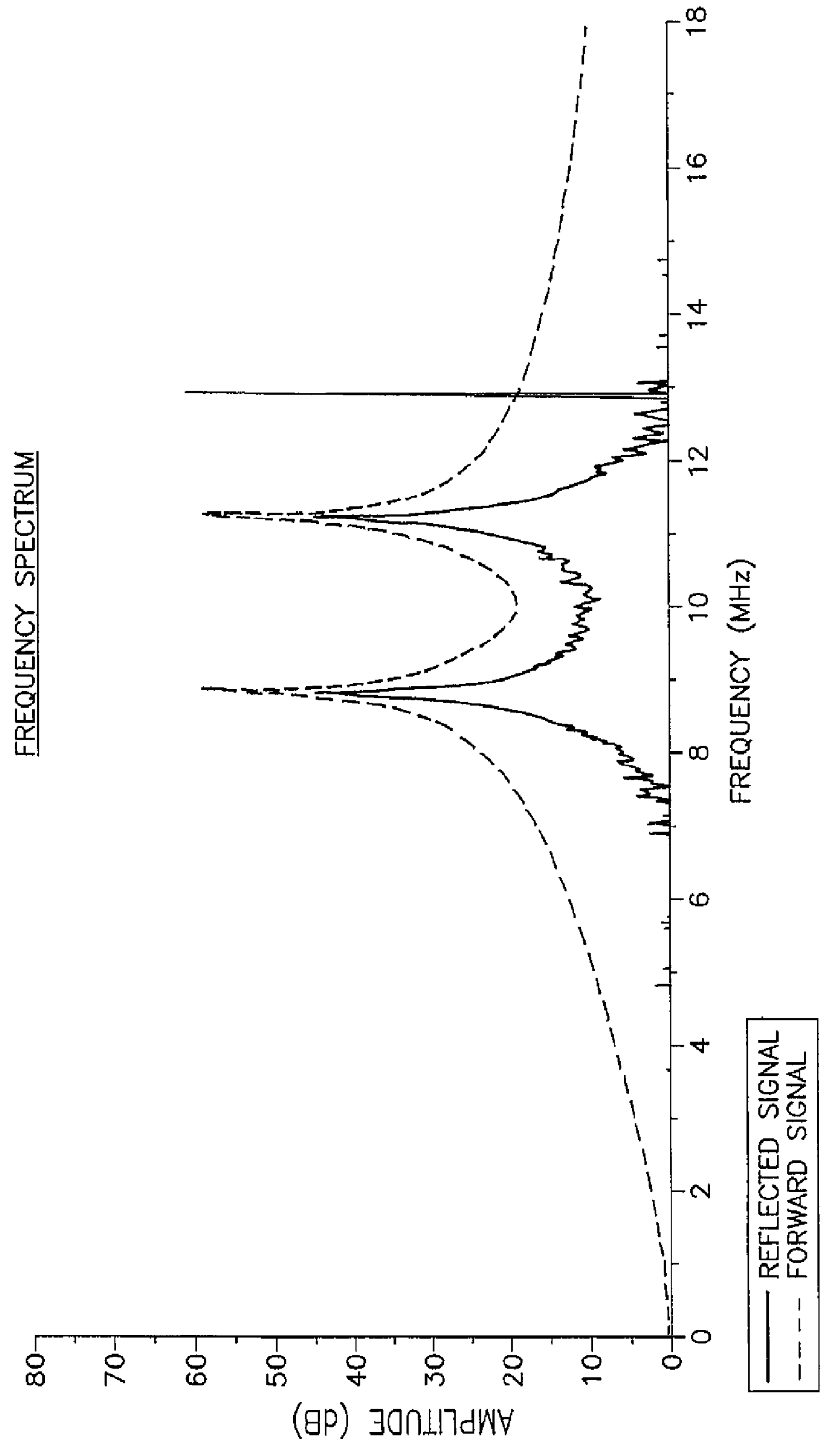
FREQUENCY SPECTRUM
AMPLITUDE (dB)
0
10
20
30
40
50
60
70
80
FREQUENCY (MHz)
0
2
4
6
8
10
12
14
16
18
REFLECTED SIGNAL
FORWARD SIGNAL

FIG.7A

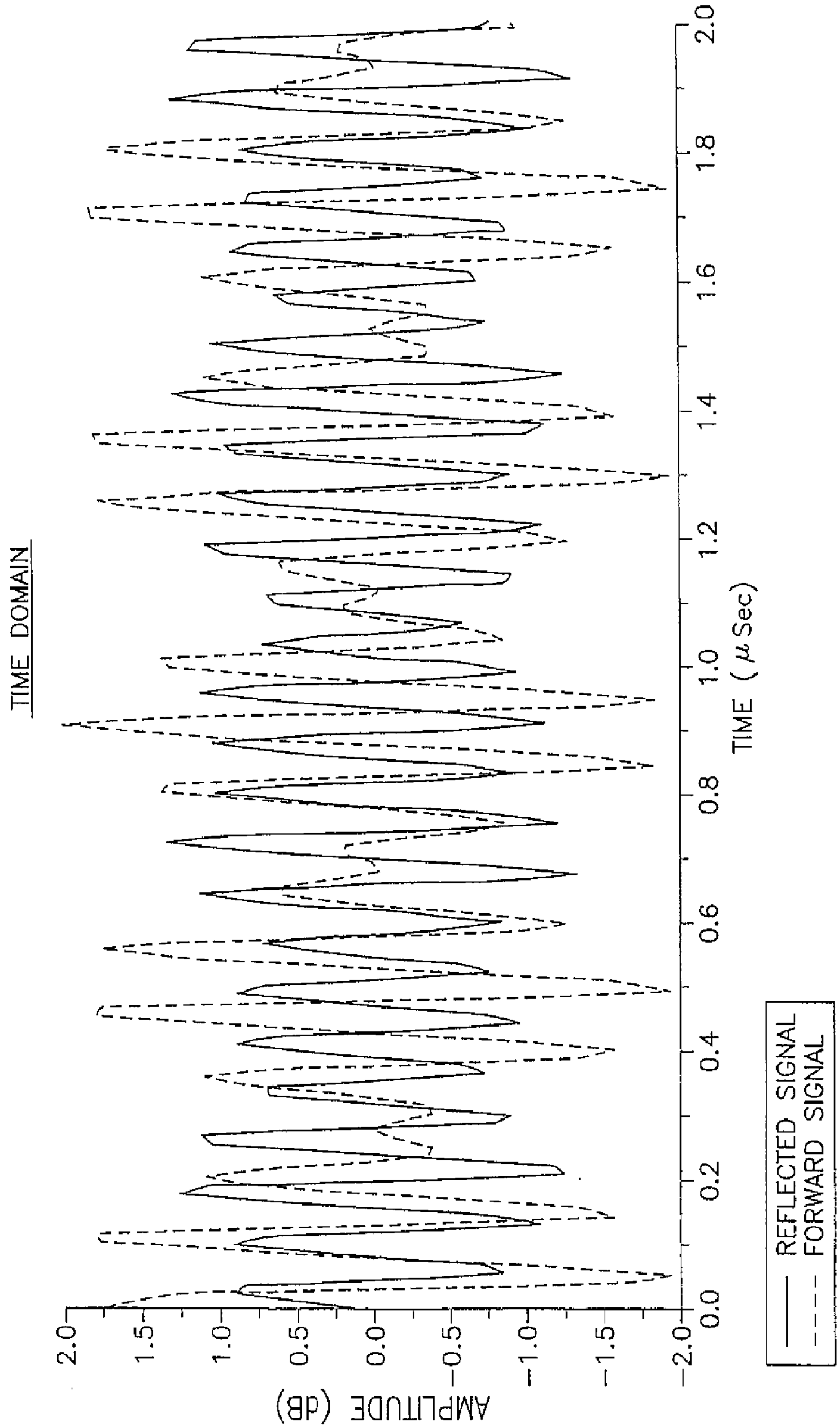
TIME DOMAIN
AMPLITUDE (dB)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
TIME (μSec)
REFLECTED SIGNAL
FORWARD SIGNAL

FIG.7B

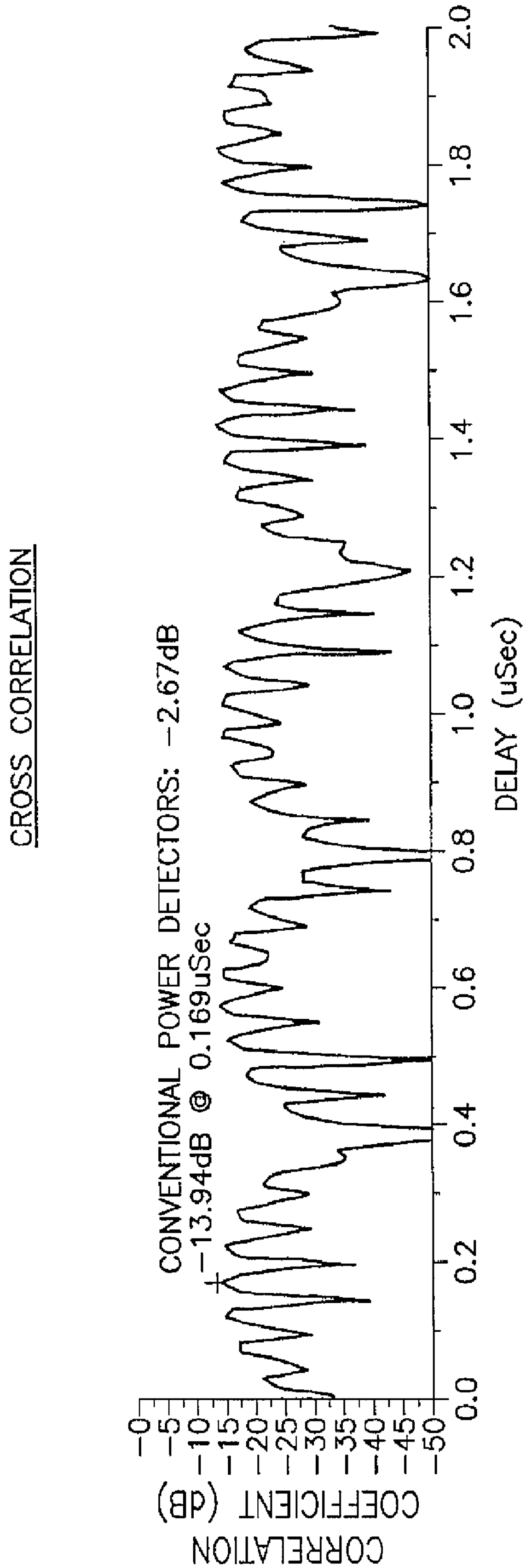
CROSS CORRELATION
CONVENTIONAL POWER DETECTORS: −2.67dB
−13.94dB @ 0.169uSec
CORRELATION COEFFICIENT (dB)
0
−5
−10
−15
−20
−25
−30
−35
−40
−45
−50
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
DELAY (uSec)

FIG.7C

VSWR ESTIMATION USING CORRELATION TO SUPPRESS EXTERNAL INTERFERENCE

TECHNICAL FIELD

This invention relates generally to wireless transmissions and, more specifically, relates to antenna usage in wireless transmissions.

BACKGROUND

This section is intended to provide a background or context to the invention disclosed below. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived, implemented or described. Therefore, unless otherwise explicitly indicated herein, what is described in this section is not prior art to the description in this application and is not admitted to be prior art by inclusion in this section. Abbreviations that may be found in the specification and/or the drawing figures are defined below at the end of the specification but prior to the claims.

In a wireless transmission system, a transmitter is coupled to an antenna through a cable/connector system. Assuming an ideal transmission system, there will be no reflected power in a reflected signal (or, put another way, there is no reflected signal). That is, the transmission power in the "forward" signal is all applied through the cable/connector system to the antenna. Real transmission systems, however, have some reflected power in a reflected signal due to, e.g., impedance mismatch somewhere in the cable/connector system or antenna.

Cellular operators need a way to monitor, in real-time, the condition of the antenna and its cable/connector system. The accepted indicator of this quality is the VSWR or, equivalently, the return loss. Return loss is the ratio of the forward and reflected powers, converted to dB. Most commonly, directional couplers, bridges or circulators are used to separate the two power signals (forward and reflected power signals) followed by detectors to quantify their respective amplitudes. While the forward signal tends to be quite pure, the reflected signal is returning from the antenna and may be accompanied by extraneous energy, e.g., "noise".

Recent advances in complex modulation, multiple carriers and especially co-siting can make the task of monitoring the condition of the antenna and its cable/connector system more difficult than in the past. As an example for complex modulation and multiple carriers, typically, the log detectors used for this are not true power detectors (i.e., do not calculate true root-mean-squared power or measure heating in a load, or the like) so the result depends on the nature of the signal. For example, between a single CW carrier and a wideband CDMA or an LTE carrier (which resembles Gaussian noise), all at the same output power, the detector output could vary up to as much as about 5 dB. As one example, the "noise" in the reflected signal may be due to other transmitters electrically combined with the desired transmitter or from co-sited transmitters coupling in through the antenna. Either way, a reflection detector will report more power than the reflection itself is producing, resulting in a lower return loss which may cause a false alarm. That is, since the return loss is a ratio of the forward and reflected powers, anything that erroneously increases the reported reflective power will decrease the return loss (assuming the forward power is stable), and an alarm can be reported due to the artificially reduced return loss.

It would be beneficial to improve monitoring the condition of the antenna and its cable/connector system.

SUMMARY

This section contains examples of possible implementations and is not meant to be limiting.

An exemplary embodiment is a method, comprising accessing a plurality of sets of correlation values. Each set of correlation values corresponds to a correlation performed between a number of first samples and a same number of second samples. The sets of correlation values were determined by aligning the number of the first samples with a selected set of the second samples and then sliding the number of first samples across the second samples to select different sets of the second samples. The first samples are samples of a forward signal transmitted over a cable/connector system to one or more antennas, and the second samples are samples of a reflected radio frequency signal that comprises a reflected version of the forward signal. The method includes determining a maximum value from the plurality of sets of correlation values, and associating the maximum value with a return loss of the cable/connector system.

Another exemplary embodiment is a computer program product comprising program code for executing the method according to the previous paragraph. A further exemplary embodiment is the computer program according to this paragraph, wherein the computer program is a computer program product comprising a computer-readable medium bearing computer program code embodied therein for use with a computer.

An additional exemplary embodiment is an apparatus comprising a memory comprising a plurality of sets of correlation values. Each set of correlation values corresponds to a correlation performed between a number of first samples and a same number of second samples. The sets of correlation values were determined by aligning the number of the first samples with a selected set of the second samples and then sliding the number of first samples across the second samples to select different sets of the second samples. The first samples are samples of a forward signal transmitted over a cable/connector system to one or more antennas, and the second samples are samples of a reflected radio frequency signal that comprises a reflected version of the forward signal. The apparatus includes circuitry configured to perform at least the following: determining a maximum value from the plurality of sets of correlation values; and associating the maximum value with a return loss of the cable/connector system. The circuitry may comprise one or more processors. A further exemplary embodiment is at least one integrated circuit comprising the apparatus of this paragraph. Another exemplary embodiment is a base station comprising the apparatus of this paragraph.

Another exemplary embodiment is an apparatus, comprising means for storing plurality of sets of correlation values, each set of correlation values corresponding to a correlation performed between a number of first samples and a same number of second samples, the sets of correlation values determined by aligning the number of the first samples with a selected set of the second samples and then sliding the number of first samples across the second samples to select different sets of the second samples, wherein the first samples are samples of a forward signal transmitted over a cable/connector system to one or more antennas, the second samples are samples of a reflected radio frequency signal that comprises a reflected version of the forward signal. The apparatus further comprises means for determining a maximum value from the plurality of sets of correlation values, and means for associating the maximum value with a return loss of the cable/connector system. A further exemplary embodiment is at least one integrated circuit comprising the apparatus of this paragraph. Another exemplary embodiment is a base station comprising the apparatus of this paragraph.

BRIEF DESCRIPTION OF THE DRAWINGS

In the attached Drawing Figures:

FIG. **1** illustrates an exemplary system in which the exemplary embodiments of the instant invention may be practiced;

FIG. **2** is a chart of measurement error versus isolation;

FIG. **3**A is a block diagram of a portion of a transmitter including (a portion of) an exemplary VSWR apparatus;

FIG. **3**B is a block diagram of a portion of a reception path used as a portion of an exemplary VSWR apparatus;

FIG. **4** is a block diagram of an exemplary logic flow diagram that illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, and/or functions performed by logic implemented in hardware, in accordance with exemplary embodiments of this invention;

FIG. **5**A is a frequency spectrum chart and FIG. **5**B is a time domain chart of forward and reflected signals for a 20 dB antenna load without interference, and FIG. **5**C is a chart of cross correlation results for the forward and reflected signals illustrated in FIGS. **5**A and **5**B;

FIG. **6**A is a frequency spectrum chart and FIG. **6**B is a time domain chart of forward and reflected signals for a 20 dB antenna load and 0 dB isolation with interference, and FIG. **6**C is a chart of cross correlation results for the forward and reflected signals illustrated in FIGS. **6**A and **6**B; and

FIG. **7**A is a frequency spectrum chart and FIG. **7**B is a time domain chart of forward and reflected signals for a 14 dB antenna load and 0 dB isolation with interference, and FIG. **7**C is a chart of cross correlation results for the forward and reflected signals illustrated in FIGS. **7**A and **7**B.

DETAILED DESCRIPTION OF THE DRAWINGS

Before proceeding with description of additional problems with conventional systems and how exemplary embodiments address these problems, reference is now made to FIG. **1**, which illustrates an exemplary system in which the exemplary embodiments of the instant invention may be practiced. In FIG. **1**, a user equipment (UE) **110** is in wireless communication with a wireless network **100** via a wireless link **115** with base station **107** (such as an eNB or NodeB), which is an LIE base station (in this example) providing access to and from the wireless network **100**. The user equipment **110** includes one or more antennas **128**.

The network **100** includes a base station **107**. Although an LTE base station is used herein as an example, the exemplary embodiments are applicable to any wireless transmission system. The base station **107** includes one or more processors **150**, one or more memories **155**, one or more network interfaces (N/W I/F(s)) **165**, and one or more transceivers **160** (each comprising a transmitter, Tx, **161** and a receiver, Rx, **162**) interconnected through one or more buses **157**. In the transmitter **161**, a VSWR estimation apparatus **120** is used to perform VSWR estimation in accordance with exemplary embodiments of the instant invention. The location, as indicated by reference **120**, of the VSWR estimation apparatus is merely exemplary. Portions **120-1** of the VSWR estimation apparatus **120** may be included after the Rx and Tx antenna paths are combined (as shown by reference **120-1**), or portions **120-2** may be implemented in the transmitter **161**. There are multiple locations in a transmission path **192** (and also in part of the reception path **193**) where some or all of the VSWR estimation apparatus **120** may reside. The one or more transceivers **160** are connected to one or more antennas **158**. The one or more memories **155** include computer program code **153**, which in this example comprises VSWR estimation control functionality **130**, which may partially or completely perform and/or control VSWR estimation. The one or more memories **155** and the computer program code **153** are configured to, with the one or more processors **150**, cause the base station **107** to perform one or more of the operations as described herein. The VSWR estimation control functionality **130** may be implemented in the computer program code **153** (executed by the one or more processors **150**), or implemented in hardware such as logic in an integrated circuit as described below, or as some combination of computer program code and hardware.

The one or more network interfaces **165** communicate over networks such as the networks **173**, **175**. The base station **107** may communicate with other base stations using, e.g., network **173**. The network **173** may be wired or wireless or both and may implement, e.g., an X2 interface. The base station **107** may use the network **175** to communicate with a core portion of the wireless network **100**.

The computer readable memory **155** may be of any type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The processor(s) **150** may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, general or special purpose integrated circuits, microprocessors, digital signal processors (DSPs) and processors based on a multicore processor architecture, as non-limiting examples.

As stated above, there could be noise in a reflected signal that causes a reflection detector to report more power than the reflection itself is producing, resulting in a lower return loss which may cause a false alarm. In order to obtain adequate accuracy, it is generally necessary to suppress the interfering signals by roughly 25 dB or more. But, depending on the tolerable error (see the RL, Return Loss, Estimation Error), the isolation could be more or less as shown in FIG. **2**. The "RL_ANT" are return losses of the antenna system. The required isolation is usually obtained through some combination of power level in order to determine at least the second samples.

embodiments disclosed herein are capable of minimizing or even eliminating the means normally taken to maintain adequate isolation. For instance, exemplary techniques disclosed herein provide discrimination between the reflections of the signal that are emanating from the desired transmitter versus interference that couples in from other sources (e.g., a transmitter co-sited with the transmitter that transmits the original signal and receives the reflected signal).

Turning to FIG. **3**A, a block diagram is shown of a portion **300** of a transmitter **161**, including an exemplary VSWR apparatus **120**. It should be noted that FIG. **3**A, for simplicity, concentrates on the transmission path and does not show the reception path (see FIG. **1** from the antenna(s) **158** to the receiver, Rx, **162**). However, this not to be construed as limiting. The portion **300** includes one or more power amplifiers **320** coupled to a cable/connector system **310**, which is coupled to the antenna **158**. The delay caused by the cable/connector system **310** is D/2 in this simple example. The

VSWR apparatus **120** includes in this example sampling circuitries **340** and **345**, buffers **155-1** and **155-2**, memory **155-3**, a correlator **370**, and VSWR estimation control functionality **130**. In this example, the one or more power amplifiers **320** and the VSWR estimation apparatus **120** are implemented in an integrated circuit (IC) **390**, such as an application-specific integrated circuit (ASIC). The VSWR estimation control functionality **130** therefore may be implemented as logic in the IC **390**. However, some or all of the VSWR estimation control functionality **130** may be implemented in computer program code **153** (e.g., stored as firmware/software in memory **155**, see FIG. **1**) and executed by a processor **150**, e.g., formed as part of the IC **390**.

It should be noted that although only one ASIC is shown, there may be multiple ASICs or other hardware elements. For instance, the sampling circuitry **340** could be implemented by one ASIC, the sampling circuitry **345** could be implemented by another ASIC, and the memories **155**, correlator **370**, and VSWR estimation control **130** implemented by a third ASIC. Furthermore, aspects of the embodiments may be performed by hardware, software (executed by hardware), or some combination. This is really an implementation detail, trading off items like cost, space, VSWR reporting speed, and the like, but the general approach is independent of this.

The operation of the portion **300** of the transmitter **161** and of the VSWR apparatus **120** is described in relation to FIG. **3**A and also in relation to FIG. **4**. FIG. **4** is a block diagram of an exemplary logic flow diagram that illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, and/or functions performed by logic implemented in hardware, in accordance with exemplary embodiments of this invention.

In an exemplary embodiment of the instant invention, rather than using individual forward and reflected signal power detectors, a sampled version (e.g., set **380** of samples) of the composite transmitted signal waveform **330** is correlated with a sampled and delayed version (e.g., set **350** of samples) of the reflected signal waveform. The delay, d, is varied from, in an exemplary embodiment, zero to the longest delay (e.g., (W_{Max}) expected which is in the order of 1.5 μsec (microseconds) for a typical base station site. The longest delay expected may be 2×ANT_cable_length/velocity_of_propagation, where ANT_cable_length is the antenna cable length and velocity_of_propagation is the velocity of propagation in the cable for a particular example that considers only the cable/connector system **310**. However, as described below, this is merely an example and the longest delay may be dramatically different from the formula just presented. A forward signal is aligned with a reflected signal, the correlation is calculated, the forward signal is slid relative to the reflected signal, correlation is calculated, and this process continues until the forward signal is slid by some amount relative to the reflected signal. The maximum value in the set of correlations is found and is, e.g., converted to dB. The maximum value represents the best estimate of the return loss and the delay (at the point of the maximum value) represents the time and therefore the distance to the reflection. Any component of the reflected signal that is not just a scaled version of the transmitted signal does not contribute to the correlation and is thus suppressed.

The example of FIG. **3**A uses a sampling point **341** for at least the sampling of the forward signal. Thus, the indicated delay, D, is for the cable/connector system **310**. However, this is merely exemplary, and the sampling of at least the forward signal **335** could occur at many different locations in the transmission path **192**, e.g., at location **342**, prior to the one or more power amplifiers **320** and as such can occur in the baseband **343**. This is indicated by reference **335-1**, which is a baseband version of the forward signal **335** that is transmitted. For this example, the sampling occurs without use of the demodulator **387**. In this case, the transmission path **192** can start in the baseband **343** and conclude in the antenna(s) **158**. Furthermore, in this case, the delay D can be quite large and include time delays for the power amplifier(s) **320**, filters (not shown) if used, and other electronics.

In terms of using the exemplary sampling point **314**, a signal waveform on the input **321** is transmitted (block **410** of FIG. **4**) by the one or more power amplifiers **320**. A version of the amplified radio frequency signal waveform is shown as **330**, which includes many symbols (in this example), a portion of which is shown as "... TX_{k-2}, TX_{k-1}, TX_k, TX_{k+1}, TX_{k+2} ...", and a radio frequency version of the forward signal is illustrated by reference **335-2**. The forward RF signal **335-2** is sampled at a particular sampling rate (e.g., in megasamples per second, Msps) by the sampling circuitry **340**, where in one example the sampling occurs after demodulation by the demodulator **387**. The set **380** of samples includes in this example M samples, a portion of which is shown as "... S_{k-2-d}, S_{k-1-d}, S_{k-d}, S_{k+1-d}, S_{k+2-d} ...", where each S is a symbol corresponding to a symbol TX in the amplified waveform **330**. To compute the correlation, a fixed length (e.g., M-length) set **380** of samples of the transmitted forward RF signal **335-2** is taken and stored in, e.g., a temporary buffer **155-1** (block **420** of FIG. **4**). Then, e.g., after some defined delay from the start of this buffering operation (e.g., the first of the M samples or some other reference point), another fixed length (e.g., P-length) set **350** of samples of the reflected waveform **355** is taken (block **430**) by the sampling circuitry **345** (block **430** of FIG. **4**, which includes a demodulator **397** from which the samples **350** are generated) and is stored (block **430**) in, e.g., another temporary buffer **155-2** (although it should be noted the two buffers **155-1** and **155-2** could be a single large buffer). The set **350** of samples includes in this example P samples, a portion of which is shown as "... ΓS_{k-2-D}, ΓS_{k-1-D}, ΓS_{k-D}, ΓS_{k+1-D}, ΓS_{k+2-D} ...", where Γ is the reflection coefficient and each S is a symbol corresponding to a symbol TX in the amplified waveform **330**. It is noted that the sampling circuitry **345** may occur before or after Rx and Tx paths are combined or at other locations in the Tx path. In particular, one possibility is shown in FIG. **3**B, which shows a block diagram of a portion of a reception path **193** used as a portion of an exemplary VSWR apparatus. In this example the portion includes an ADC (analog-to-digital converter **388**) and part of the receiver **162**, including at least a demodulator **399**, which produces the set **350** of samples. It is noted that typically P will be greater than or equal to M, although this is not a limitation.

A sample by sample correlation against the reflected signal waveform is performed by the correlator **370**, which in an example is a set of logic operations implemented in the IC **390** (or may be performed by software executed by hardware, or both). In one example, the correlator **370** starts at one end of a "delay" range (e.g., delay=0) in (one possible) block **440** ("Start at delay=0") and the cross correlator **370** performs correlation (block **450**) between the forward waveform in the set **380** of samples and the reflected waveform in the set **350** of samples. Correlation may be defined as follows:

$$CC[k] = \sum_{d=0}^{d_{Max}} f^*[k]g[k-d],$$

where CC[k] is a correlation result **371**, the "*" denotes complex conjugation, ƒ[k] is the set **350** of samples, and g[k] is the set **380** of samples. Each CC[k] has a set of M correlation coefficient values, and there will be $d_{Max}+1$ sets of results **371** in this example.

The final result **371** is stored (block **450**; the storage may be to memory **155-3**), the delay, d, is modified (e.g., incremented) in block **455**, and the measurement performed again and repeatedly until the entire "delay" range (e.g., from d=0 to $d=d_{Max}$) has been covered. More particularly, in block **460**, it is determined if the delay is at the other end of the delay range (e.g., $d=d_{Max}$). If not (block **460**=No), correlation is performed by the correlator **370** again (block **450**). A maximum search of the results **371** stored in memory **155-3** then yields the return loss estimate.

The use of a delay and a delay range is one example, but since the memories **155-1** and **155-2** may be implemented using indices such as those used in circular buffers or other buffers, the calculations may be performed using indices instead (where an index can be converted to a delay). Furthermore, it will typically be the case that a number Z, of the M samples will be used to compare with a number Z of the P samples. FIG. **3**A therefore also illustrates that a number Z of five (in this example, typically Z will be much higher, such as **128** or more samples) samples in the set **380** having indices X through X+4 are aligned (block **440**) with the number Z of five samples in the set **350** having indices Y through Y+4. A correlation is performed and the result is stored (block **450**). The number, Z, of samples in the set **380** is slid across the samples in set **350** (block **455**). If a maximum index (for the samples in the set **350**) is not reached (block **455**=No), another correlation is performed in block **450**. The correlation formula from before may be used, where ƒ[k] is a number Z from the set **350** of samples, and g[k] is a number Z from the set **380** of samples, the ƒ[k] is slid relative to g[k] for each correlation, and d_{Max} is $Y_{Max}-1$. Each CC[k] has a set of Z correlation coefficient values, and there will be $d_{Max}+1$ (i.e., Y_{Max}) sets of results **371** in this example. Furthermore, since each index (X or Y) corresponds to a sample period, the indices corresponding to and can be converted to delays.

For instance a first correlation after alignment in block **440** is performed using X to X+4 samples of the set **380** and Y to Y+4 samples of the set **350**. The next correlation is performed using X to X+4 samples of the set **380** and Y+1 to Y+5 samples of the set **350** (i.e., the X to X+4 samples of the set **380** are slid to Y+1 to Y+5 samples of the set **350**). The next correlation is performed using X to X+4 samples of the set **380** and Y+2 to Y+6 samples of the set **350** (i.e., the X to X+4 samples of the set **380** are slid to Y+2 to Y+6 samples of the set **350**). This continues until the final correlation is performed using X to X+4 samples of the set **380** and $Y+Y_{Max-Z}$ to $Y+Y_{Max}$ samples of the set **350** (i.e., the X to X+4 samples of the set **380** are slid to $Y+Y_{Max-Z}$ to $Y+Y_{Max}$ samples of the set **350**), where Y_{Max} is the maximum index in the set **350**. For instance, M and P could be 4096 (e.g., for a sample rate of 76.8 MHz), Z might be the first 128 samples (for instance), the alignment would start at both M, P=0, and end after the 128 samples have been slid by all of the 4096 samples in the P samples (e.g., Y_{Max}=4096−128−1).

If block **460**=Yes, in block **470**, the maximum value in the results **371** stored in **155-3** is determined, as is the delay corresponding to the maximum value. Determining the delay is optional. In block **480**, the maximum value is converted to dB (e.g., using dB=20 log(maximum value)). It is noted that the process of performing the correlation may be performed to also determine the correlation values in dB and therefore block **470** would find the maximum value in dB. In block **490**, the return loss estimate or an indication thereof (i.e., the maximum value in dB) is output as output **396**, e.g., to one of the processors **150** (see FIG. **1**). This may be used to determine (block **490**) whether an alarm is suitable and, if so, to output (block **490**), if desired, an indication of the alarm. Alternatively or in addition, one or more function(s) may be performed in response to the alarm (block **490**).

It is noted that the examples above start at d=0 and end at $d=d_{Max}$. However, the reverse can be true, the starting point can be $d=d_{Max}$ and the ending point can be d=0. Furthermore, the set **380** of samples is delayed and the set **350** of samples is not in the examples. However, the opposite may also be true, the set **350** of samples may be delayed and the set **380** of samples may not be delayed. It is also noted that the sliding (see block **455**) of the forward signal samples "across" the reflected signal samples is a "movement" of the forward signal samples relative to the reflected signal samples. That is, the reflected signal is effectively kept stationary while the forward signal is moved. In the example of FIG. **3**A, this is done by increasing the Y index value relative to the number Z of samples in the set **380** of forward signal samples. However this could also be done by decreasing the Y index value relative to number Z of samples in the set **380** of forward signal samples. That is, X aligns with Y in the example above, then X aligns with Y+1 . . . ; it could also be the case that X aligns with Y, then X aligns with Y−1 . . . , so that the number Z of samples in the set **380** go "backwards" through the samples in the set **350**.

As illustrated by reference **372**, the output is Γ when d=D. Also, as illustrated by reference **373**, the reflection coefficient F occurs looking outward from a beginning of the cable/connector system **310** toward the antenna **158**.

In an example, the VSWR estimation control functionality **130** may cause the operations in blocks **420-490** to occur. For instance, the signal(s) **381** may be used by the VSWR estimation control functionality **130** to load the correlator **370** with a selected delay, d, and to modify or cause to be modified the delay, d. As another example, the signal(s) **381** may be used by the VSWR estimation control functionality **130** to cause the sampling circuitry **340** to take the samples at an appropriate time. In a further example, the sampling circuitry **340** is internally programmed to take the samples at the appropriate times, and the signal(s) **381** is/are used to inform the VSWR estimation control functionality **130** (and/or the correlator **370**) that the temporary buffers **155-1**, **155-2** are full. In an additional example, the cross correlator **370** performs the cross correlations automatically and outputs the results **371** to the memory **155-3** and the signal(s) **381** are used to inform the VSWR estimation control functionality **130** as to the completion of all the correlations. Still other embodiments are possible, and the examples presented here should not be construed as being limiting.

As a demonstration of the capabilities, consider the following. First, transmit two CW carriers at equal power into an antenna load that has a 20 dB return loss. FIG. **5**A is a frequency spectrum chart and FIG. **5**B is a time domain chart of a forward RF signal **335-2** and a reflected signal **355** for a 20 dB antenna load without interference. FIG. **5**C is a chart of cross correlation results **371** for the forward and reflected signals illustrated in FIGS. **5**A and **5**B. It can be seen by FIG. **5**C that an exemplary embodiment of the instant invention determines a −20.02 dB (at 0.169 μsec) return loss estimate in dB, which is very close to the 20 dB antenna load.

Consider now the same situation but with an interfering carrier added. The interfering carrier is at the same power level as the desired carriers, which is equivalent to 0 dB of isolation. The interfering carrier may be assumed to be, e.g., caused by a co-sited base station such as an eNB. FIGS. **6**A, **6**B, and **6**C illustrate this example. FIG. **6**A is a frequency spectrum chart and FIG. **6**B is a time domain chart of forward and reflected signals for a 20 dB antenna load and 0 dB isolation with interference, and FIG. **6**C is a chart of cross correlation results for the forward and reflected signals illustrated in FIGS. **6**A and **6**B. The extent of the interference is evident from the spectral chart (FIG. **6**A) and from the time domain chart (FIG. **6**B), where the interference is clearly swamping out the desired signals. In fact, conventional power detectors would report a 2.9 dB return loss although the return loss is really 20 dB. This would be a false alarm. But, using the apparatus and techniques disclosed herein, the error is reduced to only approximately 0.2 dB (that is, 20 dB actual return loss minus the 19.86 dB estimated return loss, or about 0.2 dB).

At a load return loss of 14 dB, which is more typical of the most sensitive alarm threshold, the error is roughly 0.1 dB as shown in FIG. **7**C (i.e., 14 dB actual return loss minus the 13.94 dB estimated return loss). And, for lower return loss, the error reduces further. See FIGS. **7**A, **7**B, and **7**C, where FIG. **7**A is a frequency spectrum chart and FIG. **7**B is a time domain chart of forward and reflected signals for a 14 dB antenna load and 0 dB isolation with interference, and FIG. **7**C is a chart of cross correlation results for the forward and reflected signals illustrated in FIGS. **7**A and **7**B.

Embodiments of the present invention may be implemented in software (executed by one or more processors), hardware (e.g., an application specific integrated circuit), or a combination of software and hardware. In an example embodiment, the software (e.g., application logic, an instruction set) is maintained on any one of various conventional computer-readable media. In the context of this document, a "computer-readable medium" may be any media or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer, with one example of a computer described and depicted, e.g., in FIG. **1**. A computer-readable medium may comprise a computer-readable storage medium (e.g., memory(ies) **155** or other device) that may be any media or means that can contain or store the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer.

If desired, the different functions discussed herein may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the above-described functions may be optional or may be combined.

Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

It is also noted herein that while the above describes example embodiments of the invention, these descriptions should not be viewed in a limiting sense. Rather, there are several variations and modifications which may be made without departing from the scope of the present invention as defined in the appended claims.

The following abbreviations that may be found in the specification and/or the drawing figures are defined as follows:

ADC Analog-to-Digital Converter
ASIC Application-Specific Integrated Circuit
CDMA Code Division Multiple Access
CW Continuous Wave
dB decibel
eNB evolved Node B (e.g., LTE base station)
FFT Fast-Fourier Transform
IC Integrated Circuit
LTE Long Term Evolution
Msps Megasamples per second
PA Power Amplifier
RF Radio Frequency
RL Return Loss
Rx Reception or Receiver
Tx Transmission or Transmitter
VSWR Voltage Standing Wave Ratio

What is claimed is:

1. A method, comprising

accessing a plurality of sets of correlation values, each set of correlation values corresponding to a correlation performed between a number of first samples and a same number of second samples, the sets of correlation values determined by aligning the number of the first samples with a selected set of the second samples and then sliding the number of first samples across the second samples to select different sets of the second samples, wherein the first samples are samples of a forward signal transmitted over a cable/connector system to one or more antennas and the second samples are samples of a reflected radio frequency signal that comprises a reflected version of the forward signal;

determining a maximum value from the plurality of sets of correlation values; and

associating the maximum value with a return loss of the cable/connector system.

2. The method of claim **1**, wherein the reflected radio frequency signal is a reflected version of a radio frequency version of the forward signal, wherein reflections occur at least by one or both of the cable/connector system or the one or more antennas.

3. The method of claim **1**, further comprising determining the plurality of sets of correlation values at least by performing a correlation for the number of the first samples that is aligned with the selected set of the second samples, and performing a correlation for the number of the first samples and each different set of second samples selected by sliding the number of first samples across the second samples.

4. The method of claim **3**, wherein the number of first samples is aligned with the selected set of samples by setting a first index in a first memory of a beginning of the number of first samples to align with a second index in a second memory, of a beginning of the selected set of the second samples.

5. The method of claim **4**, wherein sliding is performed by modifying the second index for each of the different sets of second samples.

6. The method of claim **4**, wherein the sliding is performed by starting at a zero delay for the second samples and ending at a maximum delay for the second samples, each of the delays corresponding to an index in the second samples.

7. The method of claim **6**, wherein the maximum delay is determined at least by a value of twice an antenna cable length in the cable/connector system divided by a velocity of propagation of the forward radio frequency signal in the cable.

8. The method of claim 1, further comprising sampling the first samples in a transmission path from baseband to one or more antennas and sampling the second samples in the transmission path.

9. The method of claim 8, further comprising sampling the cable/connector system at a number of samples per second in order to determine at least the second samples.

10. The method of claim 8, further comprising storing a first set of M samples as the first samples and storing a second set of P samples as the second samples, and wherein the number of first samples is Z, where Z is less than the smallest of M and P.

11. The method of claim 1, wherein the associating further comprises converting the maximum value to a decibel value indicative of the return loss of the cable/connector system.

12. The method of claim 1, further comprising determining an alarm should occur based on the return loss and outputting an indication of the alarm.

13. A non-transitory computer readable medium storing a program of instructions, execution of which by a processor configures an apparatus to perform the method according to claim 1.

14. The non-transitory computer readable medium according to claim 13, wherein the non-transitory computer readable medium is a portable medium configured for insertion into a memory slot.

15. An apparatus, comprising:

a memory comprising a plurality of sets of correlation values, each set of correlation values corresponding to a correlation performed between a number of first samples and a same number of second samples, the sets of correlation values determined by aligning the number of the first samples with a selected set of the second samples and then sliding the number of first samples across the second samples to select different sets of the second samples, wherein the first samples are samples of a forward signal transmitted over a cable/connector system to one or more antennas and the second samples are samples of a reflected radio frequency signal that comprises a reflected version of the forward signal; and

circuitry configured to perform at least the following:

determining a maximum value from the plurality of sets of correlation values; and

associating the maximum value with a return loss of the cable/connector system.

16. The apparatus of claim 15, wherein the reflected radio frequency signal is a reflected version of a radio frequency version of the forward signal, wherein reflections occur at least by one or both of the cable/connector system or the one or more antennas.

17. The apparatus of claim 15, further comprising circuitry configured to perform determining the plurality of sets of correlation values at least by performing a correlation for the number of the first samples that is aligned with the selected set of the second samples, and to perform performing a correlation for the number of the first samples and each different set of second samples selected by sliding the number of first samples across the second samples.

18. The apparatus of claim 17, wherein the number of first samples is aligned with the selected set of samples by setting a first index in a first memory of a beginning of the number of first samples to align with a second index in a second memory of a beginning of the selected set of the second samples.

19. The apparatus of claim 18, wherein sliding is performed by modifying the second index for each of the different sets of second samples.

20. The apparatus of claim 18, wherein the sliding is performed by starting at a zero delay for the second samples and ending at a maximum delay for the second samples, each of the delays corresponding to an index in the second samples.

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